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DESIGN, FABRICATION AND DELIVERY OF A LINE
SELECTABLE CO LASER

UNITED AIRCRAFT RESEARCH LABORATORIES

PREPARED FOR
ROME AIR DEVELOPMENT CENTER

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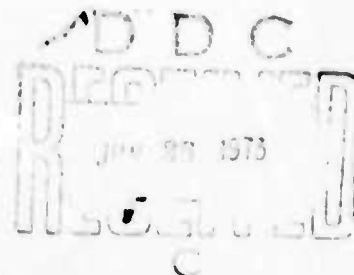
DESIGN, FABRICATION AND DELIVERY OF A
LINE SELECTABLE CO LASER

United Aircraft Research Laboratories

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Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

DESIGN, FABRICATION AND DELIVERY OF A
LINE SELECTABLE CO LASER

Dr. Carl Buczek

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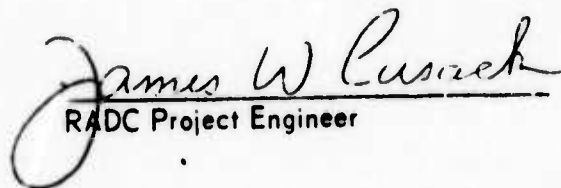
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13. ABSTRACT <p>This report discusses the technical background, design features, hardware and performance of a line selectable C O laser system. This laser was designed to operate with a high degree of amplitude stability and provides for line selection from 5.04 to 5.6 microns. The laser utilizes a three - element (two mirrors and one grating) optical resonator to achieve wavelength selectivity in a very high Q (low loss) optical configuration. This optimized configuration along with other design features has resulted in long term sealed tube operation with power outputs on single line from .1 to 1.00 W in the TEM₀₀ mode.</p>			

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SUMMARY

This report discusses the technical background, design features, hardware and performance of the line selectable CO laser system developed under Contract F30602-72-C-0248. This laser operates with a high degree of amplitude stability and provides for line selection from 5.04 to 5.6 microns. The laser utilizes a three-element (two mirrors, one grating) optical resonator to achieve wavelength selectivity in a very high Q (low loss) optical configuration. This optimized configuration along with other design features has resulted in long-term sealed tube operation with power outputs on a single line from 0.1 to 1.0 W in the TEM₀₀ mode.

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I. INTRODUCTION

The purpose of this program was to design, fabricate, test and deliver a low power, stable line selectable CO laser for atmospheric measurements at the RADC Verona test site. The CO laser developed and delivered under this program has demonstrated all of the required performance characteristics. These design requirements are:

- a) Power Output: 0.1 W in 25 selected lines in a range from 5.04 to 5.39 microns (see Table 1).
- b) Transverse Mode: TEM_{00} with linear polarization and beam expansion to 10 cm diameter.
- c) Amplitude Stability: $\pm 0.1\%$ for 1 second; $\pm 1.0\%$ for 30 minutes.
- d) Lifetime: Sealed-off operation for 200 hr and self-contained cooling capability.

Furthermore, the design was intended to optimize operation on the 5-4 transitions and extend sealed operation beyond 200 hr.

The physics of the CO laser are briefly described in Section II. These mechanisms impose severe design constraints for a single line device. The method of approach used in the design of the CO laser was based on (1) the use of a three-element optical cavity to achieve both a high Q and the required wavelength dispersion and (2) extension of CO₂ sealed tube technology to achieve long-term operation. These considerations are discussed in Section II. The resultant laser system and performance achieved are described in Sections III and IV, respectively.

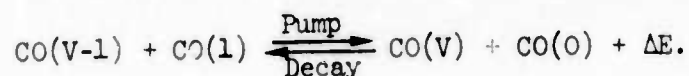
II. TECHNICAL BACKGROUND

Previous work with CO lasers has concentrated on achieving high efficiency and maximum power extraction. References 1 through 3 are representative of the published work in this area. The efforts under this contract have been concentrated on tailoring a laser for tunable single line operation over a broad spectral range. In addition, operation on the lower vibrational transitions is of special interest because of the need for atmospheric transmission measurements near 5.0 microns.

1. CO Laser Media

The single energy ladder of the CO molecule results in laser characteristics which are significantly different from that of CO₂. The vibrational energy level spacings of CO are equal except for the anharmonic defect. This energy defect provides the basis for anharmonic pumping which is the primary mechanism for producing population inversion in the CO laser. This also results in a strong temperature dependence for the lower vibrational transitions because the molecular kinetic energy is comparable to the energy level difference between the pumping molecules and the lasing molecules. Other gases (Xe, N₂ and He) are utilized to tailor the plasma characteristics.

The temperature dependence of the CO laser inversion is an important consideration in the design of a sealed-off plasma tube. This dependence can be seen from the energy balance equation which describes the anharmonic pumping mechanism.



$$\Delta E = (V-1)\Delta E_0$$

$$R_2 = R_1 e^{-\Delta E/KT}.$$

where: V = vibrational level

R_1, R_2 = reaction rates

ΔE = excess energy in forward reaction

K = Boltzman's constant

T = temperature.

For low vibrational levels or sufficiently high temperature the forward and reverse rates become comparable (i.e., $\Delta E \approx KT$, thus $R_1 \approx R_2$) and population inversion cannot be achieved. Thus, for efficient pumping of the lower vibrational levels the lowest possible temperature is desirable. However, Freed (Ref. 4) has demonstrated that Xe is essential for sealed-off operation of CO lasers. This limits the temperature to a range above -112°C where Xe freezes out of the gas mixture. The N_2 energy levels have a larger spacing than the CO and can provide some additional pumping even when the anharmonic mechanism becomes weak at low vibrational levels. However, even with a gas mixture tailored for operation on the 5-4 transition, the gain on these lines is very low. This has resulted in the requirement for the very high Q optical configuration described below.

2. Three-Element Dispersive Cavity

The low gains of the 5-4 transitions ($\sim 0.001 \text{ cm}^{-1}$) requires a very high Q

cavity even with a substantial length of gain medium. Use of a two-element mirror grating resonator to provide the optical dispersion is accompanied by absorption and scattering losses which are much too large for this kind of laser. (A high quality blazed grating for use at 5 microns may have an efficiency of only 92 percent). A low loss dispersive resonator can be realized by adding a third optical element to the cavity (Refs. 5 through 8). Such a geometry was chosen for the CO laser and is shown in Fig. 1. The 100 cm laser discharge is bounded by a 98 percent reflectivity concave output mirror (M_2) and a germanium flat (M_1) with one side uncoated. The uncoated germanium has a reflectivity of approximately 36 percent. Because of the low CO laser gain, all of the lines are below threshold with only these two mirrors in place. A 5 micron blazed diffraction grating mounted on a piezoelectric transducer is positioned immediately behind the 36 percent flat. By translating the grating the equivalent reflectivity of the mirror grating cavity can be tuned over a wide range.

$$R_{\max} = \left(\frac{\sqrt{R_M} + \sqrt{R_G}}{1 + \sqrt{R_M R_G}} \right)^2$$

$$R_{\min} = \left(\frac{\sqrt{R_M} - \sqrt{R_G}}{1 - \sqrt{R_M R_G}} \right)^2$$

R_M = reflectivity of M_1

R_G = reflectivity of the diffraction grating.

For the elements used, the extremum are 72 and 98 percent. This variation in equivalent reflectivity occurs as the spacing between the mirror and grating is varied from a resonant to anti-resonant condition. Because this high reflectivity is achieved for only the wavelength for which the grating is aligned, both

line selectivity as well as low losses are achieved with this optical configuration. In addition, the grating discriminates between polarization planes parallel and perpendicular to the grooves and thus yields a linearly polarized output beam.

III. LASER HARDWARE

In this section the CO laser hardware is described. Detailed operating instructions for the system have been delivered with the laser hardware.

The CO laser configuration consists of a three-element (two mirrors, one grating) linear cavity with a sealed-off plasma tube located between the two mirrors. The system contains the electronic components required to operate in a closed-loop mode and achieve long-term amplitude stability without operator adjustments. Also included in the laser head are beam matching optics and an expansion telescope to transform the 6 mm diverging laser output beam to a collimated 10 cm diameter beam.

The CO laser system consists of an electronic control console, laser head (shown in Fig. 2), and a closed-cycle refrigeration unit (Fig. 3). The laser head contains the laser resonator, matching optics, expanding telescope, the detector used for stabilization sensing, resonator temperature controller, and other ancillary electrical and mechanical components. The control console houses a regulated dc power supply for the plasma tube, temperature control readouts, servo electronics for closed-loop operation, line selection control and readout, and a laser power monitor. The refrigeration unit is a modified commercial item which has self-contained temperature controls and a flow switch which can be remotely activated from the control console.

A block diagram of the CO laser system is shown in Fig. 4. The system resonator temperature controller and refrigeration unit are normally always operative so that

stable operation can be achieved with a minimum warm-up period. (A 5 minute warm-up will achieve moderate stability, and 30 minutes are required for best stability characteristics).

The inside of the CO laser head with the housing and oven top plate removed is shown in Figs. 5 through 7. The major components and structural elements are indicated in these photographs. The oven structure which surrounds the entire laser resonator consists of a hinged plate configuration to which silicon rubber heating pads are bonded. These pads along with a thermal sensor and control unit provide uniform heating to minimize temperature gradients and long-term thermal drift in the resonator.

The oscillator uses a long-life sealed pyrex plasma tube with internal mirrors and employs a split discharge (single cathode twin anodes). The linear optical configuration consists of the two mirrors located at the ends of the plasma tube and a 5 micron diffraction grating. The grating along with one mirror on the plasma tube forms a secondary cavity which is tuned to anti-resonance and thus produces the equivalent of a single high reflectivity mirror for the wavelength selected by the grating orientation. Length tuning is accomplished with a piezoelectric element which translates the grating along the optical axis. Line selection is done mechanically by tilting the grating with a gear motor drive. Remote line selection is achieved by electrically reading out the grating mount position as sensed by a linear potentiometer.

The plasma tube is cooled to -90° by circulating refrigerated alcohol. This tube uses a triple concentric construction. The gas ballast (outer section) is at a pressure of only 8 torr and provides substantial thermal insulation for the alcohol

coolant. The high voltage power is interlocked to the coolant so that the discharge can be initiated only after the coolant flow switch is turned on. The plasma is held at each end by concentric metal collars which are positioned within the resonator by x,y mechanical adjustments. The main resonator structure is a truss of invar tubing to achieve both mechanical and thermal stability.

Because the output mirror is curved, the output beam has substantial divergence (4 meter wavefront curvature). This beam is allowed to expand to a diameter of approximately 10 mm before collimation by the final element in the relay optics. The 10 mm beam passes through an **Itran** window to a modified commercial 10X beam expander which results in a 100 mm (4 in.) collimated output. The Fresnel reflection off the Itran window provides a beam sample to monitor and stabilize the laser output. The sample beam is focused, mechanically chopped, and sensed with a room temperature pyroelectric detector.

The control console contains the following functional units:

- a) Plasma tube HV power supply
- b) Laser power stabilization control
- c) PZT driver amplifier
- d) Temperature control interlocks
- e) Line selector drive and readout
- f) Laser power readout
- g) Coolant flow switch
- h) Safety interlock.

The plasma tube power supply is a commercially purchased high voltage regulated power supply. Normal overload interlocks are included in its design. In addition, it has been interlocked to the coolant flow switch so that the flow must be turned on before the power supply can be operated. A ballast resistance circuit provides equal currents to both sides of the laser plasma tube.

The laser power stabilization controller contains a filtered adjustable high voltage supply for driving the PZT cylinder on the cavity grating. It also contains a hill-climbing servo (synchronous detector) which is used to provide continuous closed-loop corrections to the cavity length to maintain the laser power at its maximum level. This servo operates by synchronously detecting the power modulation in the output beam sensed by the optical detector in response to a small dither (typically 0.1%) impressed by an ac signal to the piezoelectric length transducer. The filtered output of this synchronous detector is applied to a high voltage linear amplifier which drives the PZT cylinder. Circuit functions also provide for sweeping and manually tuning the PZT voltage. The high voltage PZT drive amplifier is a commercial component which has been modified for this purpose.

The laser power is measured by the pyroelectric detector. The signal from this detector is displayed on a meter which has been calibrated to read the power level outside the laser enclosure. A full scale reading is equivalent to 1 W of optical power in the output beam. An ac signal for the power monitor is provided by mechanically chopping the beam (at a different frequency than the dither) before detection.

A readout is provided for monitoring the temperature of the laser resonator. It also indicates the continuous operation of this controller when the rest of the

system is shut off. The entire electronic controls have been built in a standard enclosed 19 in. rack cabinet. These electronic components are forced air-cooled by a fan located in the back door panel. The enclosure stands on casters for ease of movement.

IV. PERFORMANCE EVALUATION

As described in Section I, the performance goals for this laser system were in several areas: number of available laser transitions, mode quality, stability, polarization, and sealed-off lifetime. All of the program goals have been met or exceeded as demonstrated by the performance evaluation of the CO laser system.

Laser Transition: A power output of 100 mW on 16 of 25 selected transitions was required. The 25 lines are listed, along with those actually observed, in Table 1. At least 40 resolvable transitions were observed within the calibration range of the system and an additional 15 to 20 transitions beyond the calibration range are also above threshold. The long wavelength cut off is limited by the mirror reflectivity and additional transitions could be obtained in this region if it were desirable. The majority of lines were at power levels of 0.5 to 2 W with the exception of the 5-4 transition which were from 100-500 mW.

Mode Quality: Both visual observation on thermal image plates and a detector line scan across the expanded output beam indicated operation in the TEM₀₀ mode over the entire tuning range.

Stability: The laser amplitude stability was observed using a cooled Au:Ge detector element. Peak amplitude fluctuations of several tenths of a percent were present at moderate acoustic frequencies (100-1000 Hz). Over a 1 second period the mean deviation was less than 0.1 percent. The long-term stability of 1 percent over 30 minutes was obtained after a warm-up period of 30 minutes to 1 hour. This warm-up period is required because changing thermal conditions can affect the laser line gain profile which cannot be compensated for by the hill-climbing servo used to attain long-term closed-loop operation.

Polarization: The laser is plane polarized (greater than 20:1 extinction ratio) because of the diffraction grating in the optical resonator.

The performance evaluation results indicate that the CO laser system delivered will satisfy the requirements for the RADC atmospheric transmission measurements in the 5-5.4 micron region.

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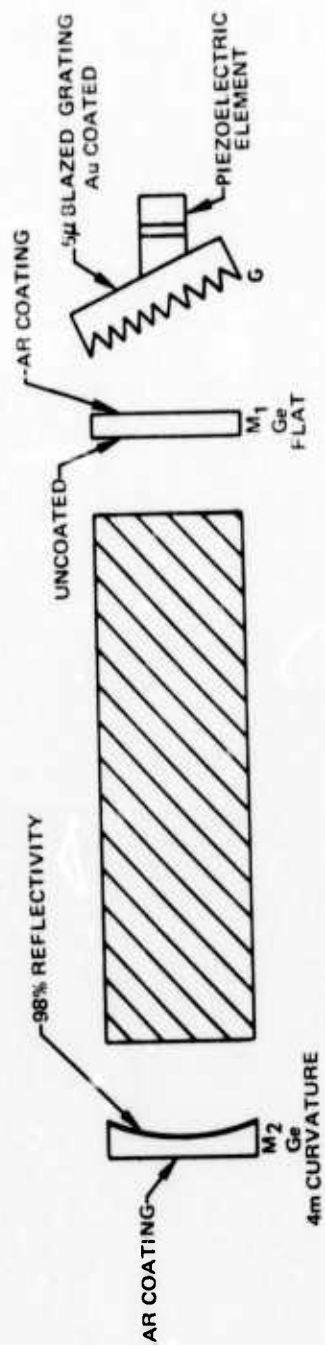
Table 1

<u>25 Desired Lines</u>	<u>Observed Lines</u>
<u>Band</u>	<u>Band</u>
5-4 --- P13, 14, 15, 16, 17	5-4 --- P14, 15, 16, 17, 18
6-5 --- P10, 12, 14, 15, 16, 19	6-5 --- P12, 13, 14, 15, 16, 17, 18, 19
7-6 --- P12, 13, 14, 15	7-6 --- P12, 13, 14, 15, 17, 18, 19
8-7 --- P9, 12, 14	8-7 --- P10, 11, 12, 13, 14, 15, 16, 17
9-8 --- P9, 14, 15, 16	9-8 --- P9, 10, 11, 12, 13, 14, 15, 16
10-9 --- P9, 12, 14	10-9 --- P9, 10, 11, 12, 13, 14, 15, 16
<u>End of Calibration Range</u>	
11-10--- P10, 11, 12, 13, 14, 15, 16	
12-11--- P11, 12, 13, 14, 15	

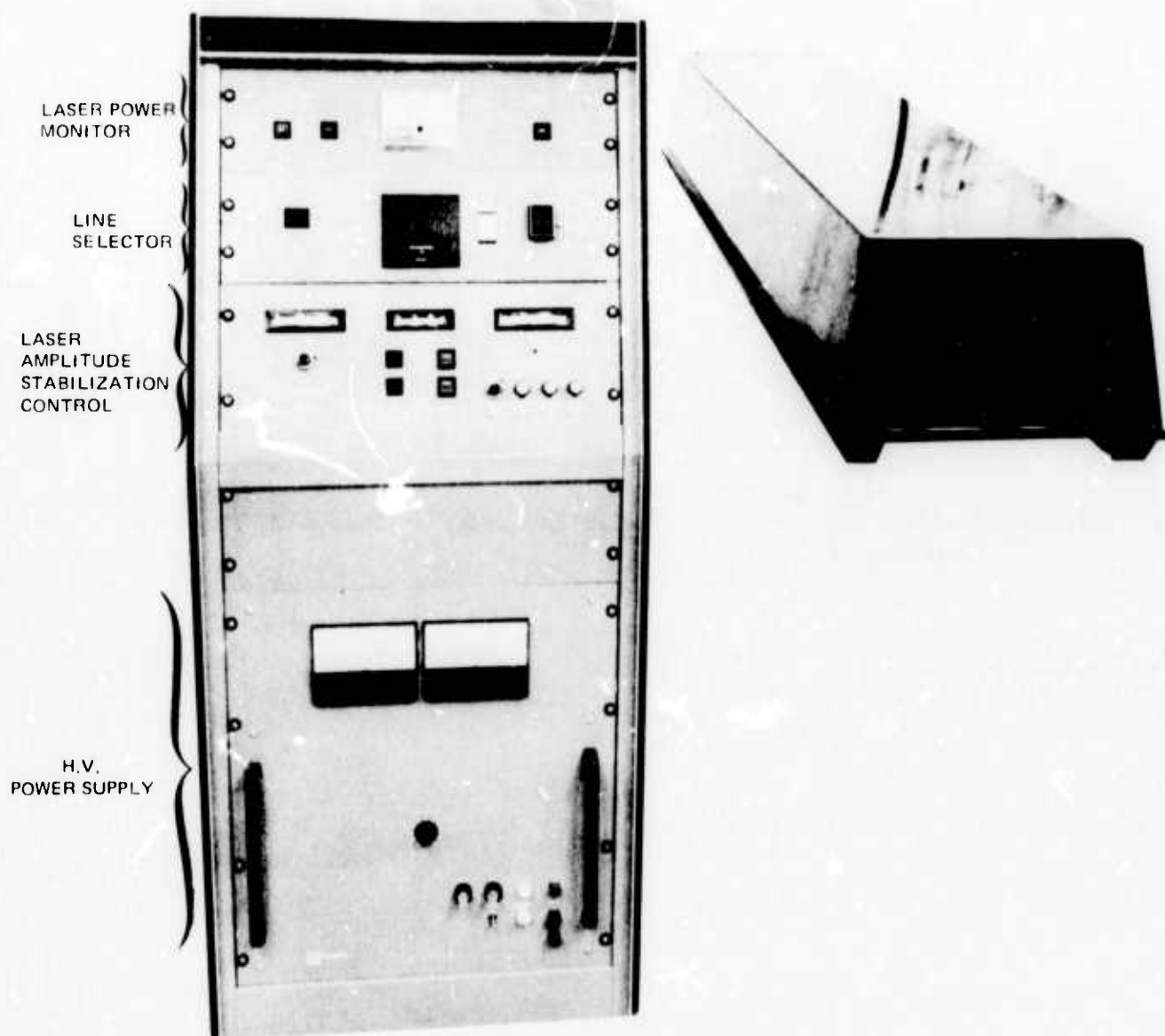
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CO LASER CAVITY GEOMETRY



CONTROL CONSOLE AND LASER HEAD



LASER REFRIGERATION UNIT

FIG. 3

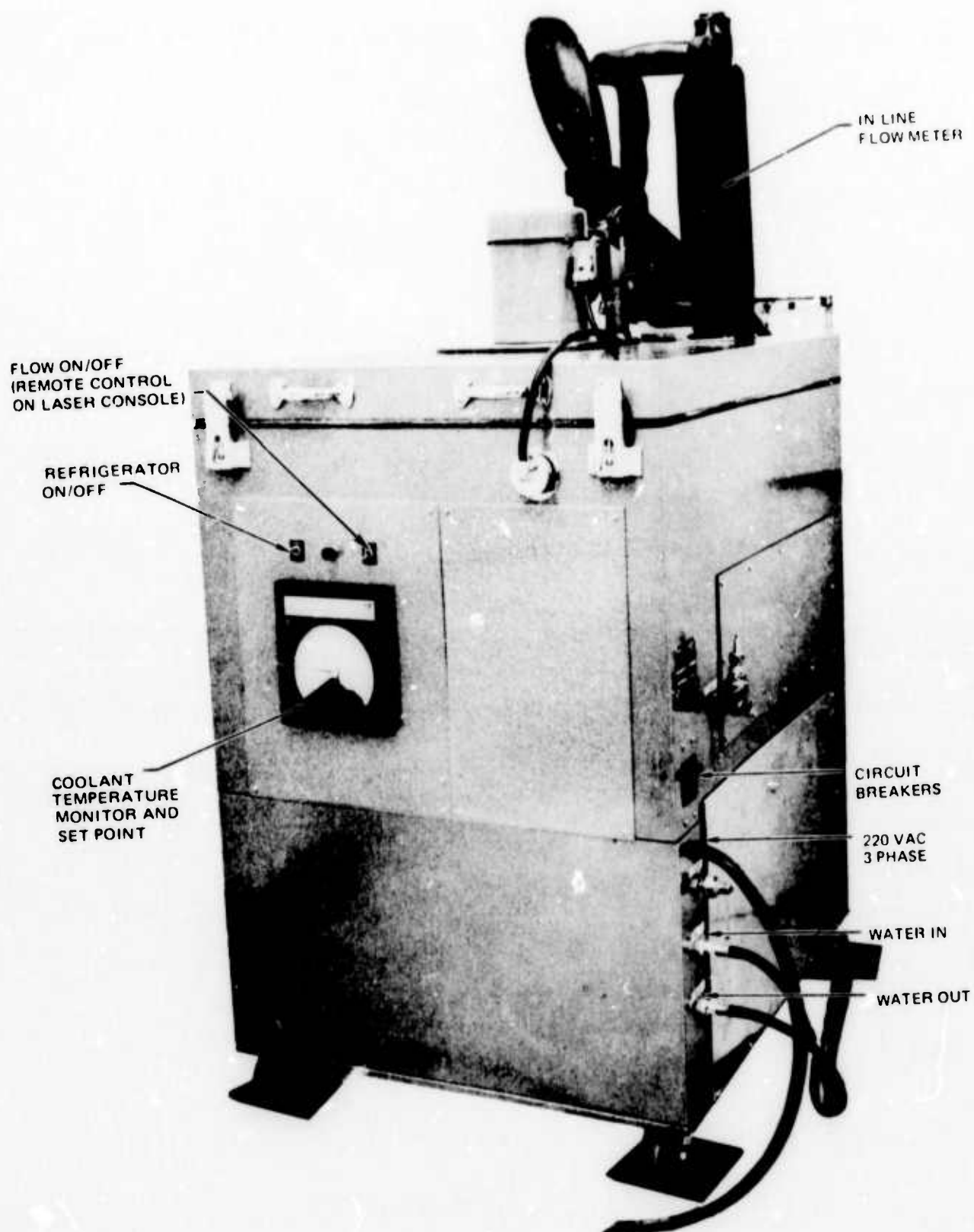


FIG. 4

CO LASER

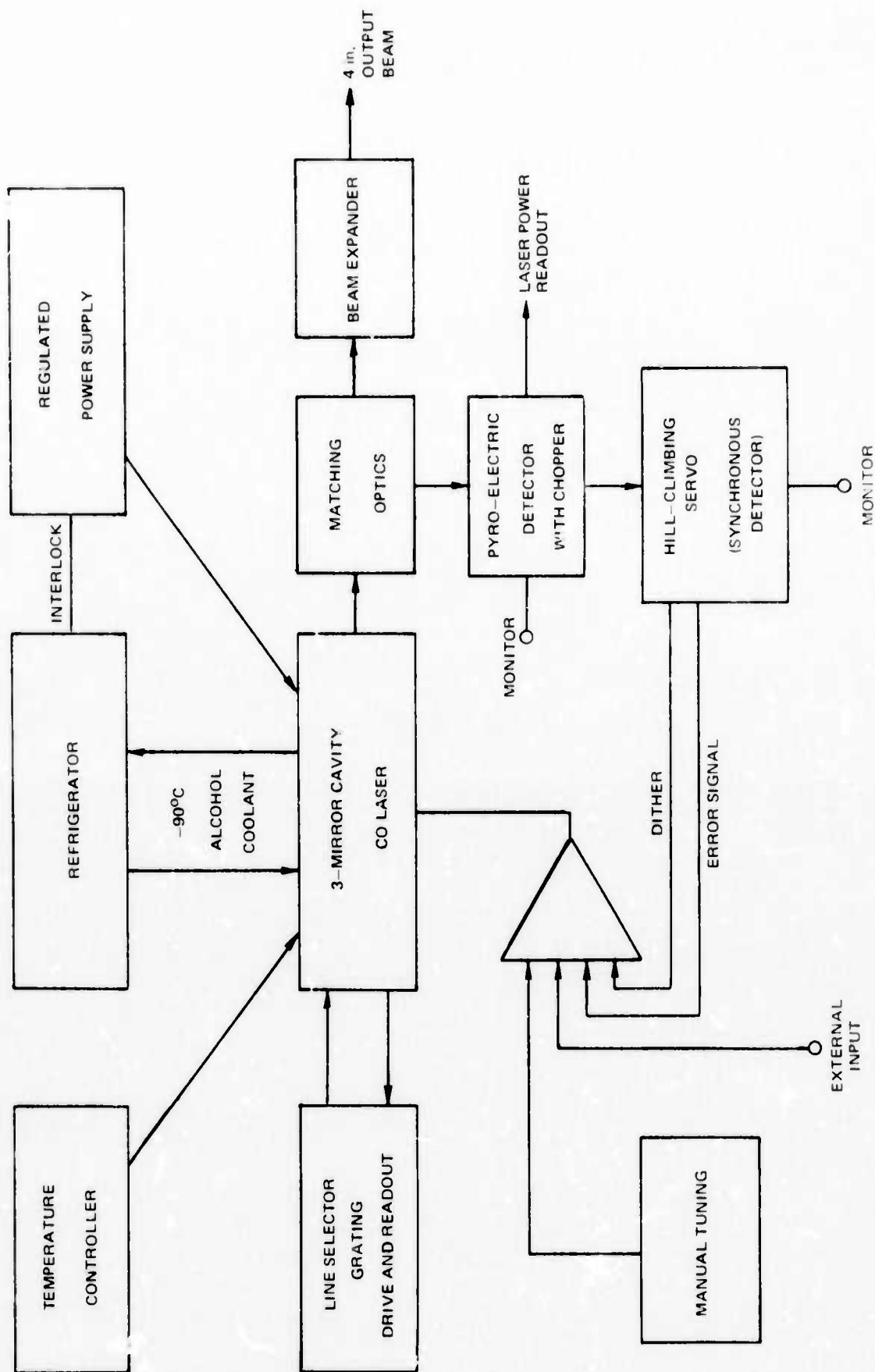


FIG. 5

LASER HEAD RIGHT SIDE VIEW

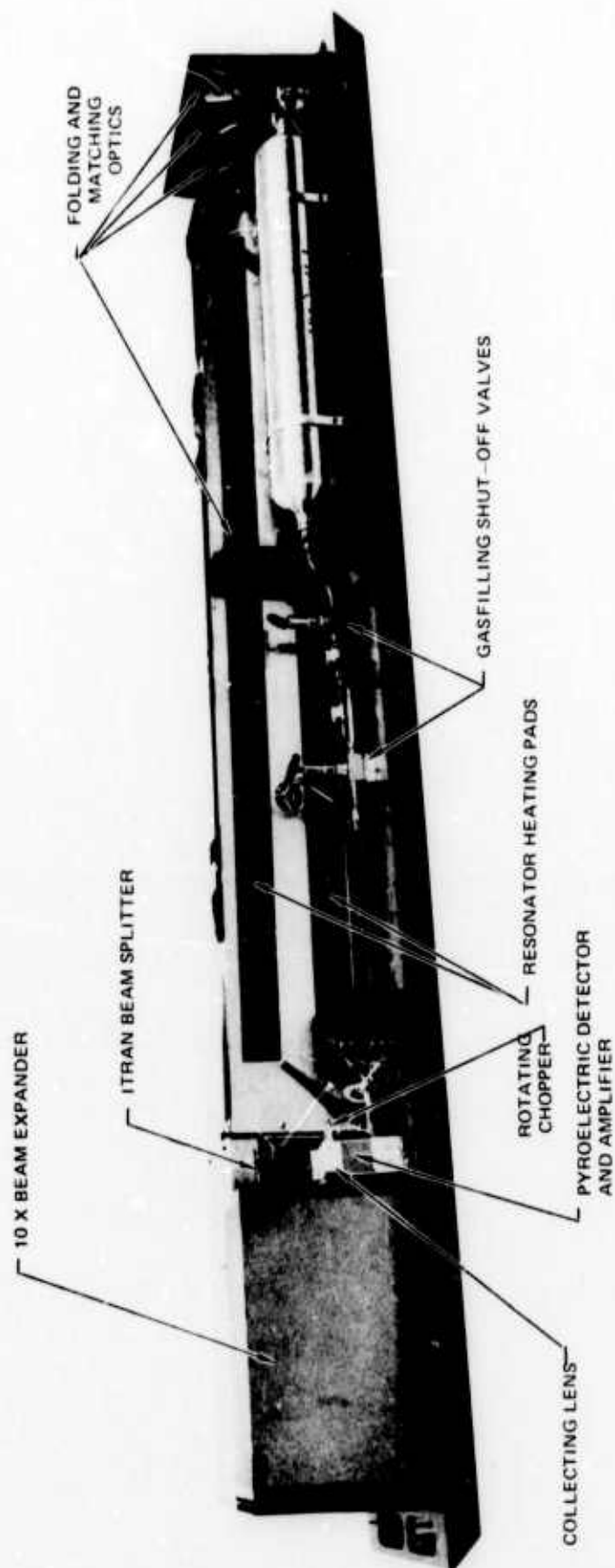


FIG. 6

LASER HEAD TOP VIEW

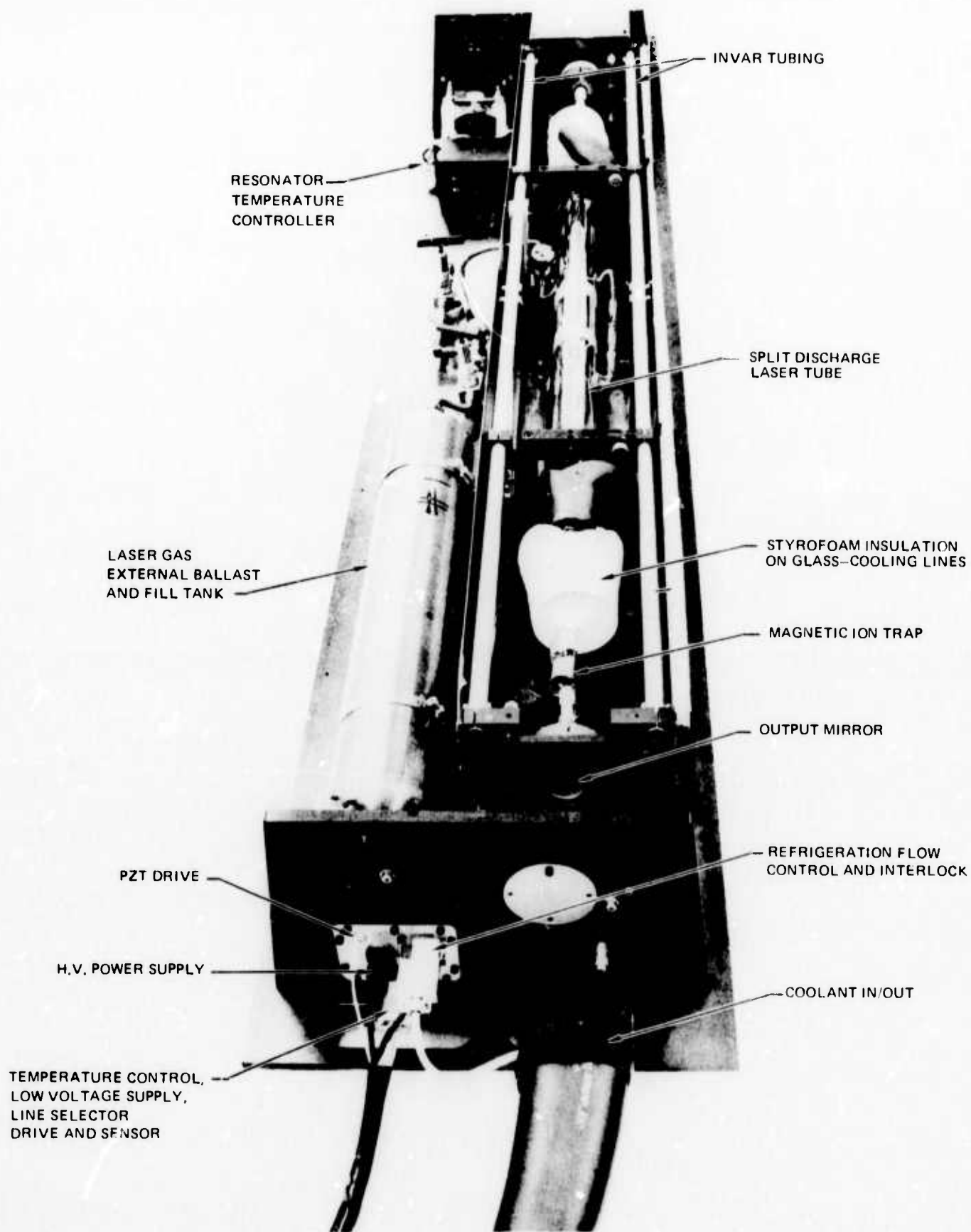


FIG. 7

LASER HEAD TOP VIEW NO. 2

THERMAL COVER OFF RESONATOR

